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Forecasting job creation from renewable energy deployment through a value-chain approach

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This paper introduces a new approach to the study of the socioeconomic impact of renewable technologies through the analysis of the reinforcing effects of the expansion of this industry and the specific characteristics of the employment along the value chain.

The method proposed is based on the collection, critical analysis and presentation of the results obtained using primary information sources. The model design includes contributions extracted from a prior analysis of the existing assessment methods, to lessen the uncertainty of the job ratios often used in these types of analysis.

One factor to be taken into account is the high degree of development in the sector and above all the maturity of the technology considered from the point of view of the industry fabric: the economy of scale and technological development actually influences the human resources needs, sometimes increasing the demand for professionals within the scope of R&D and sometimes reducing jobs in the manufacturing industry, which is gradually applying processes with a greater degree of automation. The influence of these experience curves is different for every single stage of the value chain. Trade balance of technologies is also crucial for local employment generation.

An analytical model was developed based on the above assumptions and applied to the Spanish PV industry. This industry has been playing a leading role in the expansion of renewable energy and offers a high potential towards the short-term development of the smart grids in this country.

This model represents very well the history of the Spanish PV industry reflected through the evolution of the jobs and is shown to be the foundation of a methodology for prospective studies in the social and economic impacts of renewables.

Contents

1. Introduction

The main argument for the renewable energy deployment in industrialized countries has been their contribution to reducing the environmental impacts of energy consumption. However, renewables integrate the three dimensions of sustainable development of a territory providing many other socio-economic impacts, for instance, energy security, economic growth, territorial vertebration and employment.

As many studies show, renewables have a positive effect on the balance of payments of the territory, specially in regions with a high dependence in fossil fuels [1]. As own resources are able to

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reduce imports and ensure supply without relying on energy markets, an increased share of renewable energy aims to a reduction of the trade deficit and a stabilization of the energy prices. However some authors maintain that the promotion of renewable energy over other forms of generation can be in some cases counterproductive to economic growth because of the increased costs or the shifting of other sectors [2–4]. Territorial cohesion, requiring more resource efficiency and greener economy, has been viewed too as another important issue where renewables can play an important role. Moreover, renewable energy has special implications for rural communities because large renewable installations, mainly wind farms or biomass plants, have to be sited in relatively open countryside and create jobs to increase local tax incomes among other benefits [5,6].

Regarding employment, it is fully accepted that an increase in renewable power leads to the creation of jobs [7]. Nevertheless labour intensity is not the only aspect that should be covered by a whole study about renewable employment as was indicated by [8]. Obviously the induced job losses due to the replacement of conventional sources of generation [2,9] or gains due to the increasing activity in other related sectors [10] are to be assessed. In this line, some studies have demonstrated that the exploitation of renewable energies for electricity production generates a greater number of jobs than that supplied by conventional energy plants: for every MW installed it is estimated that renewable energy sources generate between 1.7 and 14.7 times more jobs than natural gas generation plants [11] and up to 4 times more jobs than those supplied with coal [12].

Among all socioeconomic impacts, it is the employment generation which has focused most attention in the vein of the numerous reports elaborated by different types of organisations having different interests about the information. While companies are usually interested in the employment created by a specific project, public administration focuses its studies on the employment created by a stimulus programme and associations of different industries quote the total employment supported by a sector.

In general terms, most of the reports about employment in renewable energy industries are aimed on the assessment of the number of existing jobs (usually direct jobs) by means of analytical methods [12–14]. These studies are often focused on a technological area (i.e. biomass in [14] or solar thermal in [15]) and in a territory (i.e. Greece in [16] or Germany in [17].

The obtained results allow to estimate coefficients or ratios that quantify the employment created per unit of installed power or electricity from the energy sources. There are several references where some of these ratios are collected [18,19] highlighting the dispersion in the values presented as well as enough variability in the used ratios.

One problem with the array of existing studies is that they apply a wide range of methodologies, assumptions and reporting formats which make a direct comparison of their job findings – or any agregation and extrapolation – very difficult or impossible unless wide knowledge is applied.

The diversity of these ratios can be firstly justified with the different scopes of the research and analysis carried out in each of the studies when calculating the direct and/or indirect employment generated.

In general terms, the studies analysed provide two separate ratios, one for the construction and manufacture and another for the operation and maintenance stage, making it difficult to interpret in some cases exactly which stages are considered in each ratio. For example in the study carried out in Germany by Lehr [20] the installers are added to the ratio corresponding to the jobs generated in operation and maintenance, to be able to differentiate between jobs that are probably local and jobs that may be created in distant manufacturing plants. Other studies such as those by EPRI and CEC in California [21] add the jobs in the installation stage to the first of the ratios to make the distinction between temporary and permanent employment. Anyway, Kammen et al. state ''making the distinction between these two kinds of jobs is also important because the categories 'scale' differently as the industry expands'' [22] and this is definitively what this paper tries to go on with.

In terms of terminology and ratios it can be seen that in most of the studies focused on the analysis of the stage of manufacturing and construction the use of "person-year per installed MW" ratio is widely used so as to reflect the short-term character of the employment during this phase. On the other hand, if phases of operation and maintenance and fuel processing are considered the ratio of "number of jobs per MW of installed capacity", i.e., the number of people who would be needed stably to operate the plant, is quoted.

When comparing ratios between different reports, apart from knowing with security what is the timescale for which the ratios are referred to, it is necessary to put these employment numbers on a common basis specially if the estimation of the total employment associated with each technology is targeted. When adding short-term and long-term jobs the concept of job years becomes instrumental.

Even by ensuring consistency in the methods used for data collection, the interpretations obtained from employment ratios could have a high degree of uncertainty unless territory aspects, deployment of renewable technologies, maturity of industry or availability of skilled workers among others are considered [23].

The case of the wind energy in Denmark is very illustrative. According to the data from EWEA [24,25] in 2007 only 3 MW were installed in Denmark whereas 23,500 jobs were reported for the wind sector. These figures give an unrealistic ratio of 7 833 jobs/MW far from other countries with a higher amount of installed MW. Dalton and Lewis [26] compare ratio for several countries and advert how these ratios drive to confusing resuls in a first approach. Only making an interpretation of these ratios in the light of the structure and the development of the industry, differences can be explained.

On the other hand, for a given sector and territory, the time when the information is obtained has a strong effect on the ratios too. While in the 2003 EWEA report a rate of 6 jobs/MW [27] was reported for wind turbine installation in Europe, this ratio drops to 1.9 jobs/MW in the 2008 report [25], reflecting the reduction in the number of jobs relative to the installed capacity as economies of scale increase and renewable technologies mature.

In addition to the errors due to extrapolation methods, these estimates sometimes provide overall figures, i.e. the total number of jobs arising from the installation of a given power without discriminating the phases in which they are generated, the stability or temporary employment or the geographic location of the workers, and should be considered as trend and not absolute. Nevertheless these job characteristics are secondary variables whose analysis can yield valuable information for the strategic promotion of renewables at a local level.

According to the study carried out by Singh and Fehrs [12], 1 MW of wind power installed operating for one year supports 9500 h of labour that is theoretically shared as follows: 67% of the work occurred in component manufacture, 11% in installation, 20% in service and 2% in transport. The installation of a 30 MW wind farm will generate an employment of 144 people-year approximately that, distributed over 30 years, results in 4.8 stable jobs throughout the whole life of the installation. Only if the local wind power industry covers every link of the business chain, the jobs will remain in the territory but if as usual the components are acquired abroad, only an average of 1.6 jobs per year remain in the closest environment. This indicator may turn out to be even lower due to the temporary nature of some of the stages.

Definitively it is important to understand the structure and running of the sub-sector object of each study to be able to correctly interpret the employment ratios.

This paper presents a new approach to the study of the socioeconomic impact of renewable technologies through the analysis of the reinforcing effects of the expansion of this industry and the specific characteristics of the employment along the value chain.

2. Model fundamentals

Generally we can observe in the literature that employment ratios do not take always into account the different phases in which jobs are generated. In some studies ratios are divided into the construction stage or the operation and maintenance activities [28,21] but as it is known the economic activities surrounding the exploitation of renewable energy are numerous and cover all the links of the supply chain of the energy business, from the component design and manufacturing to the O&M through the assembling, the installation and the commissioning.

Accounting total jobs involved in the deployment of any renewable installation might give different results if in addition to the primary energy source and technology (statistics always differentiates solar thermal and photovoltaics), the type (isolated or grid-connected, ground or rooftop-mounted) or the size of the facilities among others are taken into account.

As can be seen, these differences are due to the labour intensity of each stage of the value chain.

We stated that renewable technologies have a common life cycle that includes 5 stages. Regarding jobs, employment characteristics were found to be rather different depending on each phase. According to the authors, Table 1 shows the basic characteristics of the jobs created in each phase of activity considered.

For instance, construction and installation, or dismantling, create higher numbers of employment but during a short period. Most stable jobs are generated during stages 1, 2 and 4 but they will be certainly local only in the operation and maintenance phase.

Jobs in R&D, design and even in component manufacturing are often located far from the territory where the renewable installation is set unless a strong industry has been developed in the region.

From the terminology used in the ratios found in the literature, jobs for construction and installation (*temporary* stages) are always reported in terms of "person-years" whereas in operation and maintenance or fuel processing (*stable* stages) it is the "number of jobs", i.e. the stable number of people who were needed for a plant to be operated. In both cases these quantities are related to one installed MW (or installed m^2 in the case of solar collectors for example). Using these ratios for a geographic area can overestimate the number of jobs as a result of recording those generated in the production of imported equipment as local or otherwise can disregard some created jobs if an exporting zone is studied.

An approach from the supply chain could distinguish these aspects and could establish the framework so as to refer jobs to other variables such as the MW produced (to be precise, to produce all the components required to install each MW) in a given technology.

To some extent this approach is close to that of other studies that consider the two phases of the life of the project, the installation and operation and maintenance, but explores in detail each of these stages. Disaggregation used allows to deduce the percentage of hours worked on as a measure of the intensity of use of each of the stages of the supply chain and make predictions based not only on the size or capacity of the installation, but also the type of installation.

On the other hand, the separation in several stages allows the use of variables other than the installed MW. In fact, labour generated at each stage is not always proportional to the installed power. This is the case for the manufacturing stages: applying a ratio referred to the installed MW gives right results only if the installed technology comes from the same territory. In other case it might induce miscalculations.

Finally, a variable to be taken into account is the degree of development in the considered sector and above all the maturity of the technology considered from the point of view of the industry fabric: the economy of scale and technological development actually influence the human resources needs, sometimes increasing the demand for professionals within the scope of R&D and sometimes reducing jobs in the manufacturing industry, which is gradually applying processes with a greater degree of automation. Some of the studies analysed assume that the employment ratios can be reduced as a result of the economy of scale and the growing experience of the renewable energy industry (the study by Heavner and Churchill [21] assumes an annual decrease of 10% in the construction ratio and 5% in the operation and maintenance ratio, while the reduction in other studies does not follow a fixed reference, for example the study by Kammen et al. [22]).

3. Model development

The proposed model is aimed to provide the number of persons that are working in a renewable sector during a given time period (one year in the case study) for which sector is defined through new installed MW, cumulated installed MW and volume of manufactured components expressed in terms of MW as well. These input data would arise from industry statistics or would represent global scenarios. How this installed power is covered, that is, the size and type of the installations has not been taken into account because these possible model variables are often out of overall statistics. To go into the employment of specific projects a new survey should be required in order to develop a new model where scale could be included.

As a result, a semi-empirical model was developed based on the following assumptions:

1. Employment in the installation of certain renewable power is the result of aggregating the jobs created in every link in the supply chain the employment intensity being different in each stage.
2. Jobs are not always related to the installed power.
3. The level of development of this sector influences the employment intensity.

Table 1
Stages considered in the study and influence on the volume and quality of employment.

	Phase	Volume of generation	Location (from higher to lower probability)	Temporary nature	Level of specialisation
1	Research, design and development	Medium	From foreign to local	Stable	Very high
2	Manufacturing	Medium	From foreign to local	Stable	Very high
3	Transport, installation and commissioning	High	From local to foreign	Temporary	High
4	Operation and maintenance	Low	Local	Stable	Medium
5	Renovation, modernization, uprating or de-commissioning	High	From local to foreign	Temporary	High

Eq. 1 fully agrees with the above assumptions and configures the model.

$$Jobs_t = \sum_i P_{i.t} \cdot I_{i,t} \quad (1)$$

where

- i is each considered link in the supply chain
- $I_{i,t}$ is the employment intensity for a given stage i into the supply chain
- $P_{i,t}$ is the referred MW for the stage i (installed MW for stages related with manufacturing, cumulated MW for O&M stages and manufactured MW for component manufacturing stages)

However the employment intensity $I_{i,t}$ is expected to depend on the time so the higher the technology development is, the lower the man-hours required to complete a production unit. This concept called "learning curve" was originally introduced in the manufacture of aircrafts in 1936 by Wright, who described a basic theory to evaluate the repetitive production of aircraft assemblies. Since then, the concept has been used in many fields. In industry, the "learning curve" applies to time and cost of production.

For the proposed model:

$$I_{i,t} = I_{i,base}\left(\frac{Cumulated\ MW_{i,t}}{Cumulated\ MW_{i,base}}\right)^{-\propto} \quad (2)$$

where $I_{i,base}$ is the employment intensity and $MW_{i,base}$ is the cumulated power for a given stage i empirically obtained and the subindex t means the time when this intensity has been evaluated. The exponent α is a correction factor related to the learning curve of the studied technology.

Such a model provides the number of jobs generated at a given time in which the installed power, accumulated power and industrial production of the different components of an installation are known or scheduled.

It should be noted that employment intensities $I_{i,t}$ are different for each technology, stage i and deployment time t, and should be obtained by means of empirical data.

Next section illustrates the method to obtain the employment intensities.

The Spanish PV industry was selected as case study not only for its recent role in the expansion of renewable energy in Spain but for its potential towards the development of the distributed generation and the smart grids in this country.

3.1. Employment intensities

Eight stages were considered to set up the supply chain of the PV technology:

1. Design and engineering
2. Silicon ingot and wafe production
3. Cells manufacturing
4. Module assembly
5. Manufacture of solar trackers
6. Manufacture of electronic components and inverters
7. System integration, assembly and installation
8. Operation and maintenance of installations (O&M)

The stage "Manufacture of solar trackers" was deliberately separate so as to facilitate the evaluation of the employment involved in fixed PV panels which is mainly the case of domestic installations. Contracting companies were included in the category "Installation".

The first phase in the development of model was focused on the analysis of jobs throughout the photovoltaic supply chain of a PV, i.e. the work force involved from the component manufacturing stage to the operation of an installation.

The raw data used came from an analysis of primary sources, the reports of activity of business associations, trade information for companies and especially the results of a survey conducted among companies.

To ensure that all data could be compared on a fair basis and to support later analysis, a data collection template was prepared. The companies of the database were contacted and were given one month to respond via an online survey. The data collection template was structured in two parts: one for qualitative assessment and one for quantitative:

- The qualitative assessment section of the template included a brief description of the company (year of establishment, company size, description of activities, etc.) as well as the selection of the part of the supply chain where its activity is focused. Other information requested included the specific kind of installation that the company works on, for instance, ground-mounted or roof-mounted and in case of both of them the percentage of activity devoted to each one.
- The quantitative assessment section was in turn divided in two parts. In the first one, the participants were asked for the number of photovoltaic megawatts that they were working on (studied, manufactured, installed, operated or maintained) during the last year MW without making a distinction about where they were finally installed. The second one was aimed to know the composition of the workforce according to different functional levels.

Data collected from the company respondents were checked to ensure their consistency through different means. For all projects we checked the web site–which was in place–of the company to corroborate the information we received. In case the template was not clear enough we also contacted the company either via email or phone.

These surveys eventually provided disaggregated information about the workforce in every single stage of the considered supply chain as recorded at the beginning of this section and seven categories of professional skills (administrative staff, maintenance staff, operators, installers, salesmen, technical consulters, managers).

Table 2 shows the results of these surveys and summarizes the total hour and skills required to accomplish eight different activities to construct, install and service 1 MW of PV in a whole, without ascertaining where the jobs are generated (in the local area or abroad, in a manufacturing firm or in a research centre) unless they are overlapped with information reflecting a particular situation.

The application of the data summarized in Table 2 to a regional level, defining its industry in terms of yearly cumulated, installed and manufactured MW is shown in the section "Results". It should be noted that only the information coming from the last column ("total jobs") has been used.

Nevertheless a first conclusion derived by the direct application of the data in Table 2 is that if the local industry has an organisation including each and every link of the supply chain, all the generated jobs will be local and all results from the last column will be aggregated giving a high employment/MW ratio. On the contrary, if as usual technology is acquired far from the site not all data must be merged in a local ratio and a higher percentage of the employment will be renounced.

Making use of the information displayed in the rows of Table 2 some commonly accepted ideas can be explained such as the

Table 2
Involved jobs for the commissioning of 1 MWp according to the stage in the supply chain and professional skill.

Jobs/MW	Managers	Technical consulters	Salesmen	Installers	Operators	Maintenance staff	Administrative staff	Total jobs
Projects/studies	0.08	0.17	0.03				0.05	0.33
Silicon	0.05				0.80		0.13	0.98
Cells	1.01	0.50			0.70		0.20	2.41
Module assembly	2.01	1.01			4.02		2.01	9.05
Solar tracker	0.97	1.04	0.84		2.55		0.97	6.37
Elect. components and inverters	0.68		0.45		0.82		0.65	2.60
Installation	1.06	1.35	0.67	2.31			0.67	6.06
Operation	0.30	0.35	0.21			0.47	0.32	1.65
Total	6.16	4.41	2.20	2.31	8.90	0.47	5.00	29.46

effect that the manufacturer develop their own technology. From the last row (labelled "Total"), we can see that technical consulters (in other words developers) hold 15% of the working time required to put in the market 1 MW of PV. This turns to 21% if the activity cell manufacturing is only taken into account and, according to the present approach, this employment is theoretically shared by all the entities involved in the activity "cell manufacturing". Then, if a specific manufacturer did not have a R&D department, these corresponding jobs (1 out of 5) would be added to those other firms or research centres and as a result the employment generated by this manufacturer would be lower.

Table 2 shows that the commissioning of 1 MW – considered as a basis of calculation, not as a proxy for the facilities – involves according to the data of 2010, 29.5 full-time direct jobs (about 51,500 h of direct labour) for a whole year's work. This rate is very similar to the 30 direct jobs per fabricated and installed MW reported by EPIA [29]. This result can be seen within the error margins generated from the difference in time between studies and more than possible differences in the study site (remember that PID is a European association), considered working days and techniques in the productive processes.

Fig. 1 shows how this labour is distributed among different stages. As Fig. 1 shows, the highest employment rate is generated during the manufacturing of the PV modules (31% of total) while the lowest occurs in the design and engineering stage (1%) followed by operation and maintenance stage (6%). The jobs involved in the design, installation and operation stages– supposed to be local jobs – make up around a quarter of the total workforce and consequently the export – import balance of technologies will be crucial for local employment generation.

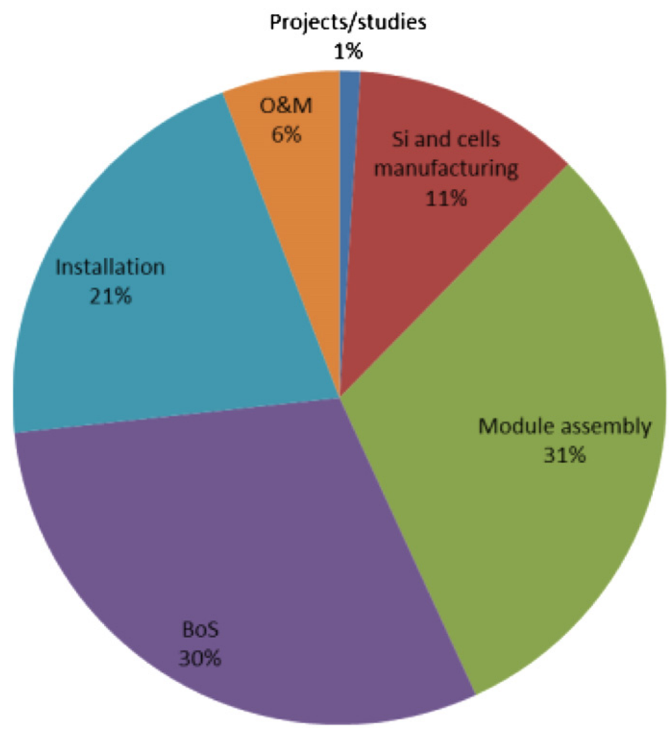


Fig. 1. Employment distribution among stages of the supply chain.

The recorded hours only include the direct activities of PV sector. As reported at the National Action Plan for Renewable Energies in Spain [30], the direct employment generates a 45% of indirect employment. In consequence, a total of 75,000 working hours or 43 jobs would be generated along the commissioning of 1 MWp.

Although Table 2 was elaborated from rough data from companies regardless of the type of installation, some insights about the effect of the type on the manpower requirements can be ascertained. For instance, an installation without tracking system would require less labour as the workforce assigned to the manufacturing of the solar trackers, 6.37 jobs per MW according to Table 2, must not be reflected.

The surveys coming from companies working in the "Installation" stage were analysed in greater depth and some differences could be observed. Final data ranged from 2.5 to 10 jobs per MW whether the works are for ground or for roof-mounted installations.

On the basis of the foregoing, 20 jobs per MW would be obtained disregarding manpower for "Solar tracking" and "Inverters" and considering 2.5 jobs per installed MW as it occurs in fixed ground-mounted installation. In the case of a particular solar tracker roof-mounted installation not 6.37 but 10 jobs per MW in the installation step have to be added which would provide 34 jobs per MW.

As previously explained, Table 2 summarizes the total jobs-year (FTE full-time-equivalent jobs) involved in the commissioning of 1 MW of PV without taking into account either the area or the exact time when they are generated. When these results are aim to be applied to a particular installations some considerations about time should be incorporated.

Accordingly, the installation of a 2 MWp power plant would employ 60 people-year as discussed above not necessarily created in the area where the facility is located. Anyway, most of these jobs (55.6 people-year, all except those of the O&M stage) would be concentrated in the first years of the installation's service life, and only if this type of plant was built without continuity solutions would this value indicate the permanent employment inherent. For this reason it is more realistic to distribute these jobs over the lifetime of the plant (25 years) resulting in nearly 2.2 stable jobs in addition to the 2.3 jobs for O&M activities. In other words, each installed MW generates 2.76 new jobs distributed as Fig. 2 shows. Among all it is the O&M stage which dominates the manpower.

3.2. Correction factor derived from learning curves

Fig. 3 shows the evolution of the ratio "jobs per installed MW" estimated from historical data of the Spanish PV industry and how the accumulated MW has been rising. We can observe an asymptotic decrease for the considered indicator along the time. According to our research, this is a result of the economies of scale and the increased experience in the renewable industry.

In consequence, learning curves for the PV case were incorporated to the model. Table 3 summarized the considered correction factors. Some differences in the learning rates for the different stages of the supply chain were assumed.

This is the main difference between this model and those that consider constant employment ratios and envisage that there is always a level of deployment of technology from which new jobs would not be generated unless disruptive measures were promoted. The way that this affects local jobs depends on the domestic industry structure.

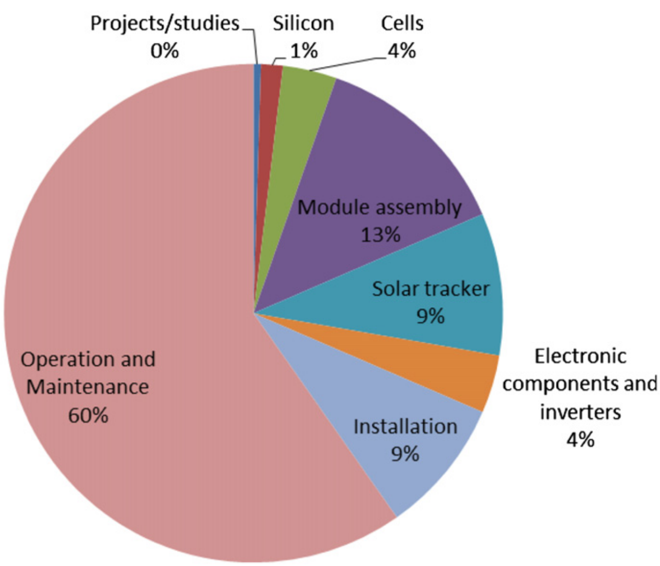


Fig. 2. Distribution of the FTE jobs created due to a 2 MW PV installation.

It also calls for a clarification of the difference between the global ratio of 29.5 jobs/ MW estimated from surveys of businesses and the estimated ratio for any year from the business association data. As explained, the jobs created in the installation of 1 MWp of photovoltaic power in a territory would be 29.5 full-time direct jobs only if all stages of the value chain take place in that territory. Certainly this is not the case.

4. Results

The employment intensities for several years other than the base calculated according to Eq. (2) are summarized in Table 4.

These intensity ratios were combined with actual manufactured, installed and cumulated MW as reported by the Spanish Association for the Photovoltaics Industry (ASIF) [31]. Table 5 compiles the information from the last activity memories of this business association.

Data from Tables 4 and 5 were introduced into Eq. (1) and total jobs for each characterized year were obtained. Partial results were added in order to obtain values comparable with those of ASIF. Table 6 shows the model results that are very close to the real data summarized in Table 7.

As a graphical summary, Fig. 4 displays actual employment data and results obtained through both a partial model only represented by Eq. (1)and a comprehensive model incorporating Eqs. (1) and (2). The first model seems to be inadequate for the forecasting of total jobs in the PV sector, offering results far from those reported by ASIF.

The advantage of using adjustment factors α as shown in Table 8 is also observed when comparing partial results as Figs. 5–7 reflect.

Table 3
Fitting parameter related with learning rates. Spanish case.

	α
Projects/studies	0.56
Manufacturing	0.15
Installation	0.56
Operation	0.42

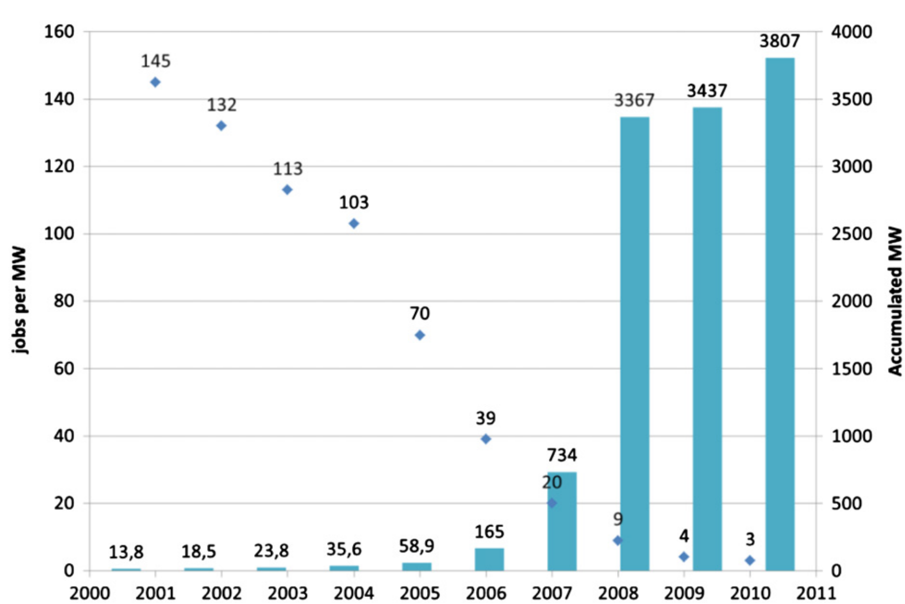


Fig. 3. Evolution of the simplified ratio jobs per MW along the time.

Table 4
Calculated employment intensities for several years $I_{i,t}$.

Year	BASE	2001	2002	2003	2004	2005	2006	2007	2008	2009
Cumulated MW	3807	13.8	18.5	23.8	35.6	58.9	165	734	3367	3437
	$I_{i,base}$	$I_{i,2001}$	$I_{i,2002}$	$I_{i,2003}$	$I_{i,2004}$	$I_{i,2005}$	$I_{i,2006}$	$I_{i,2007}$	$I_{i,2008}$	$I_{i,2009}$
Projects/studies	0.33	7.71	6.54	5.68	4.54	3.42	1.92	0.83	0.36	0.35
Silicon	0.98	2.29	2.19	2.11	1.99	1.84	1.58	1.26	1.00	1.00
Cells	2.41	5.61	5.37	5.17	4.86	4.51	3.87	3.09	2.46	2.45
Module assembly	9.05	21.03	20.12	19.38	18.24	16.92	14.49	11.59	9.22	9.19
Solar tracker	6.37	14.80	14.16	13.64	12.84	11.90	10.20	8.15	6.49	6.47
Inverter	2.60	6.03	5.77	5.55	5.23	4.85	4.15	3.32	2.64	2.63
Installation	6.06	141.12	119.76	104.00	83.01	62.61	35.17	15.25	6.50	6.42
Operation	1.65	17.52	15.49	13.94	11.77	9.52	6.18	3.30	1.74	1.73

Table 5
Manufactured (M), installed (I) and cumulated (C) MW-$P_{i,t}$ in Eq. (1)—as reported by ASIF [9].

	Reported MW	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Projects/studies	I	2.5	4.7	5.3	11.8	23.3	106.1	569	2633	70	390
Silicon	M										
Cells	M	36.8	50.85	59.3	90	70.1	85	115	195	23	100
Module assembly	M	36	47.25	58.9	108.5	82.6	90	154.5	498	269	699
Solar tracker	M								414	55	166
Inverter	M								741	271	1330
Installation	I	2.5	4.7	5.3	11.8	23.3	106.1	569	2633	70	390
Operation	C	13.8	18.5	23.8	35.6	58.9	165	734	3367	3437	3807

Table 6
Total jobs as model results.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Manufacturing	963	1224	1447	2417	1713	1633	2145	9714	3598	11,075
Installation	372	594	581	1033	1539	3935	9149	18,040	475	2494
O&M	242	287	332	419	561	1020	2423	5863	5933	6296
Total jobs	**1577**	**2105**	**2360**	**3869**	**3813**	**6588**	**13,717**	**33,617**	**10,006**	**19,865**

Table 7
Total jobs as reported by ASIF.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Manufacturing		1760	1530	1683	1895	2485	2890	8000	2712	4640
Installation		280	350	1000	1200	2640	10,115	18,000	3188	2460
O&M		400	800	1000	1000	1320	1445	5300	5400	4500
Total jobs	**2000**	**2440**	**2680**	**3683**	**4095**	**6445**	**14,450**	**31,300**	**11,300**	**11,600**

Table 8
Fitting parameter related with learning rates. German case.

	α
Projects/studies	0.43
Manufacturing	0.14
Installation	0.55
Operation	0.23

The effect of the regulation and incentives policies in the employment generation was not considered as an independent variable in the development of this model. Anyway, incentives usually result in the installation of new power and model incorporating power is somehow able to show the gradual increase in the number of full-time-equivalent jobs starting in the year 2004 probably induced by the Royal Decree (RD) 436/2004 as well as the huge reduction suffered during 2009 two years later of the establishment of a new energy tariffs system.

As shown in Fig. 8 the same model was applied to German photovoltaic sector [20]. Employment intensity factor was estimated from baseline factors (column named $I_{i,base}$ in Table 4) and real MW data. Fitting parameters α in Table 8 were slightly different from those referred to the Spanish case.

5. Conclusions

A model capable of estimating the employment created by a sub-sector in a local scale incorporating variables with the dependence on the industry structure or its deployment has been presented.

This model incorporates employment intensities along the supply chain, the position of every stage in this one and the professional profiles of the workers were developed, as a proper approach to identify phases of job creation as well as quality, temporality or even geographical location of the employment.

In addition, the disaggregation of data according to a supply chain has been shown as a proper methodology under which

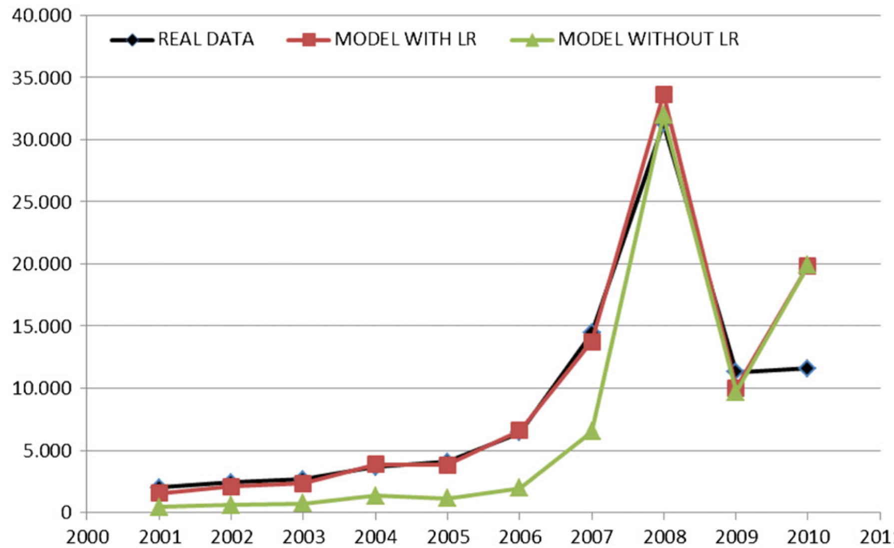


Fig. 4. Real and estimated total jobs comparison (Spanish case).

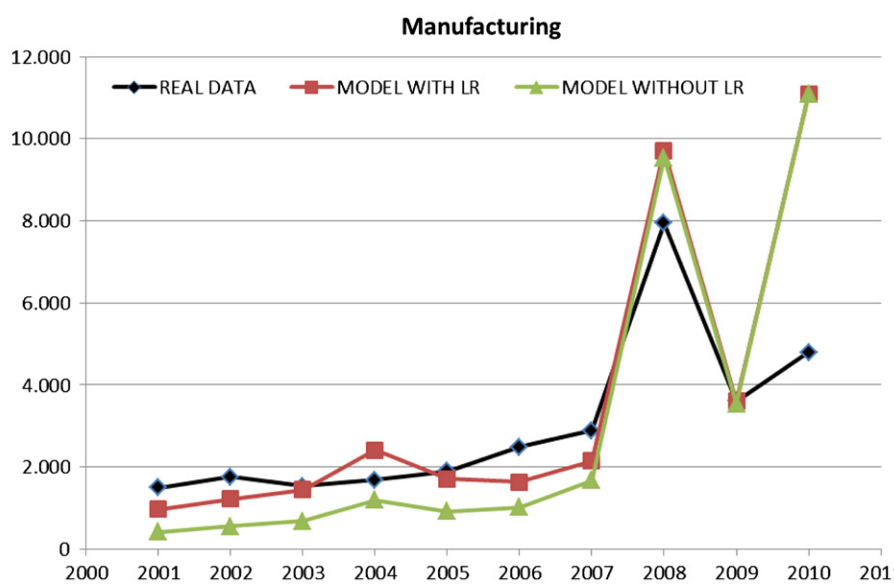


Fig. 5. Comparison of real and estimated jobs in the manufacturing stages (Spanish case).

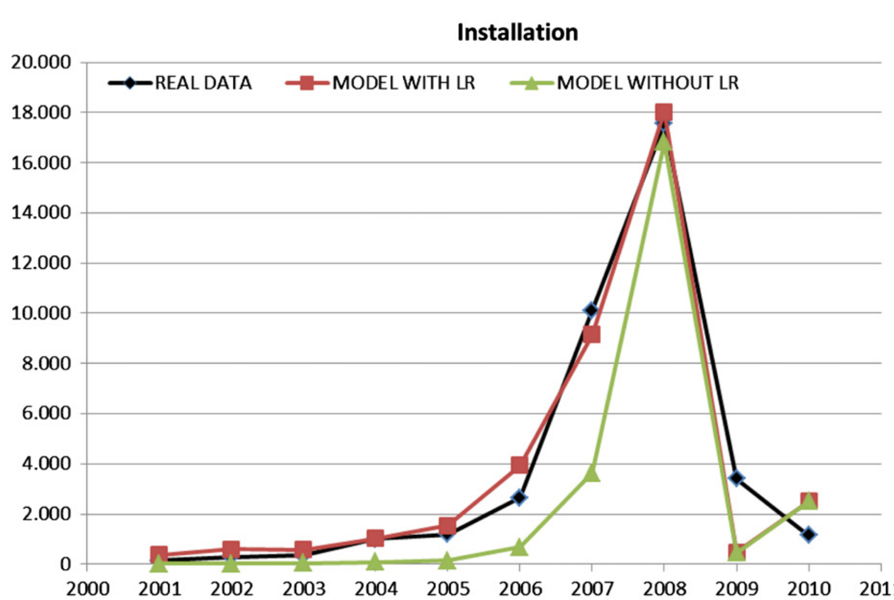


Fig. 6. Comparison of real and estimated jobs in the installation stage (Spanish case).

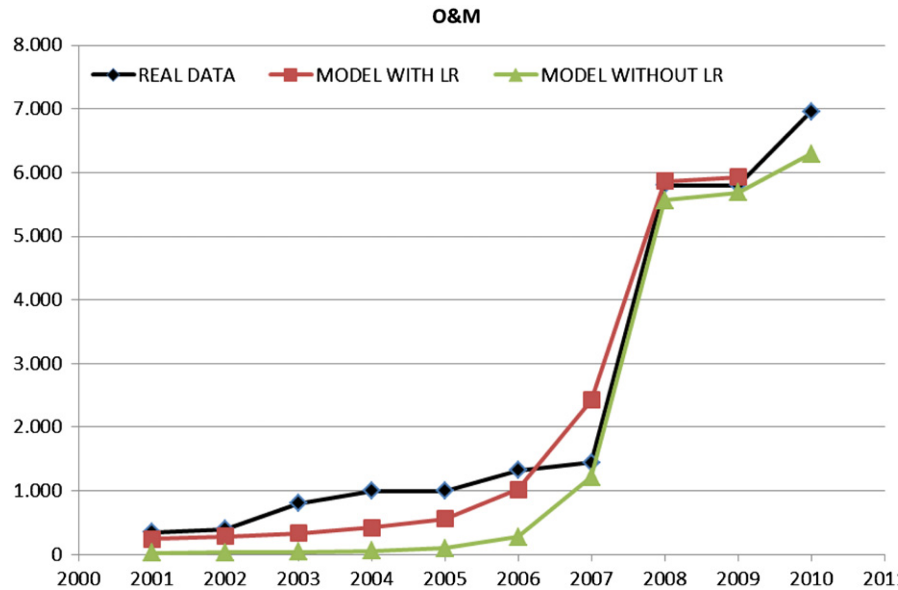


Fig. 7. Comparison of real and estimated jobs in the O&M stage (Spanish case).

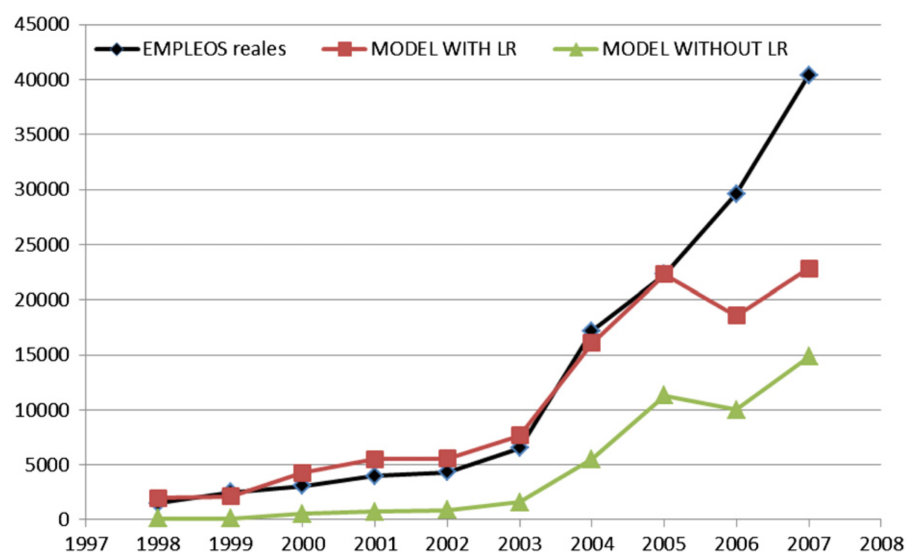


Fig. 8. Real and estimated total jobs comparison (German case).

some commonly acepted facts can be clarified i.e. why territories with a strong manufacturing industry have higher employment ratios or why manufacturing companies developing technology show a higher manpower than those import ideas.

The model provides the number of persons that are working in a renewable sector during a given time period, the sector being defined in terms of new installed MW, cumulated installed MW and MW of manufactured components in the same period, and paves the way to identify opportunities for local renewable deployment as it could be able to recognise ripple effects, scale impacts, key jobs, innovation possibilities and synergies with adjacent sectors, among others.

This model is very different to those that consider constant employment ratios and envisage that there is always a level of deployment of technology from which new jobs would not be generated unless disruptive measures were promoted. The way that this affects local jobs depends on the domestic industry structure.

The results of the model fitted very well to data from the Spanish PV industry and clearly identified the impact on the employment of public policies during the last ten years.

Finally the model was also successfully tested with data from German industry concluding that a model of this type can be used as a tool to evaluate different scenarios and to identify strategies for renewable energy that create the highest opportunities for social and economic development of the population without the complexity of the input–output models.

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